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RESEARCH NOTE

Determination of Fruit Ripeness Degree of 'Carabao' Mango (*Mangifera indica* L.) using Digital Photometry

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Color photographs of 'Carabao' mango fruits at different color index (CI) values or stages of ripeness were computer analyzed based on RGB, HSV, and L*a*b* color spaces. Plots of R, B, V, and L* versus CI had correlation coefficients (R^2) of 0.874, 0.915, 0.931 and 0.948, respectively. Titratable acidity (TA) and fruit firmness decreased with CI. Values of R^2 for TA were 0.917, 0.915, 0.948, and 0.977 for R, B, V, and L*, respectively; corresponding values for firmness were 0.941, 0.933, 0.941, and 0.968. R^2 of the binary and ternary color functions for TA were 0.924 and 0.947, respectively; corresponding values for firmness were 0.905 and 0.948, respectively. The results show that digital photometry – using a simple digital camera and free-access software for color analysis based on RGB, HSV, or L*a*b* systems – is a promising laboratory method for determining the ripeness degree of 'Carabao' mango fruits.

Key words: 'Carabao' mango, digital photometry, HSV, L*a*b*, RGB, ripeness indicator

Abbreviations
C – color function, CI – color index, HSV – hue saturation value/brightness, L*- lightness, LED – light emitting diode, RGB – red green blue, TA – titratable acidity, TC – total carbohydrates, TS – total sugars, TRS – total reducing sugars, TSS – total soluble solids, TSt – total starch

INTRODUCTION

Color is determined by light source, reflected light from the sample, and visual sensitivity of the observer. These determinants were defined by the Commission Internationale de l'Eclairage (CIE) in 1931 in order to simulate the visual mechanism based on the primary colors (R, G, B) and color-matching functions. The majority of color digital still cameras intended for technical applications use an array of transistors on a CCD chip, with a filter array that allows some detectors for red (R), green (G), and blue (B). Thus, a digital color image is represented in RGB form with each color component R, G, or B per pixel in the range 0 to 255 and conventionally stored using eight bits per color component. L*a*b* or CIELAB, which is another commonly used and CIE-specified measure of color, may be calculated from XYZ values. The latter are functions, in matrix form, of the RGB values. Another color space which is useful for fruit color analysis is the HSV (or HSB) system, where hue (H), saturation (S), and value/brightness (V/B) are calculated from RGB values.

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Fruit peel color is a usual indicator of fruit ripeness and quality and has been observed to correlate well with the physicochemical properties of the fruit (Domingo et al. 2012). Therefore, quantitative color analysis is expected to be useful in evaluating fruit ripeness and quality. This can be done using a simple digital camera and free-access computer software for color analysis. This digital photometric method has been applied to the determination of stages of ripeness of various fruits based on fruit surface color after transforming the RGB values into a binary or ternary color function that could be used in correlating fruit physico-chemical parameters with degree of ripeness. Ripeness determination for 'Maradol' and "Sinta' papaya varieties have been done using digital photometry (Basulto et al. 2009; Domingo et al. 2012).

The 'Carabao' mango (*Mangifera indica* L.) is a delicious variety native to the Philippines characterized by its semielliptical shape and pale green color that turns yellow as the fruit ripens. According to Nunes (2008), during the initial stages of development, the measured L* value (lightness) of the mango peel decreases then later on increases because of the development of yellowing as the fruit ripens. The a* (redness-greenness) and b* (yellowness-blueness) values also increase indicating the development of a dark green color in the earlier stages of development followed by yellowing as the fruit starts to ripen.

The present study was conducted with the following objectives: (a) determine the total soluble solids content, total sugars, total reducing sugars, pH, titratable acidity, total starch, and firmness of mango fruits at each color index (CI); (b) correlate physico-chemical properties and calculated parameters based on RGB, HSV, and L*a*b* color systems with CI; and (c) calculate color functions based on RGB values and determine their correlation with the studied chemical parameters.

MATERIALS AND METHODS

Samples and Sampling Method

'Carabao' mangoes with color index 1 (full green) were obtained from Manaoag, Pangasinan on the third week of Jan 2012. The maturity of the fruits was determined by the flotation method where fruits were placed in a 1% NaCl solution. Fruits that sank were considered mature. Mature, full green fruits free of blemishes – which were used in the study – were placed in cardboard boxes and stored at 13°C with 92% relative humidity.

A set of three fruits for image acquisition was allowed to ripen and pictures were taken when the fruits reached each stage of ripeness. Stage of ripeness was determined by visual examination of the change in peel color using the following color index (CI) values corresponding to the six stages of ripeness: 1- full green; 2 – color break; 3 - more green than yellow; 4 – more yellow than green; 5 – yellow with traces of green; and 6 – full yellow. Another set of three fruits at each stage of ripeness was withdrawn from storage and used for destructive analyses. A total of 18 fruits were used for these analyses.

Equipment

Still color photographs of the fruits were taken with a 14.1 megapixel GE digital camera. Analyses of RGB data were done on a laptop computer with Windows XP operating system using the Java applet RGB program of Byers (2006). A penetrometer (IMADA MF push-pull instrument, Japan) was used to measure fruit firmness. A pH meter (YM, PHS-25 Analog, China) was used to determine pH. Total soluble solids content was determined using a hand-held refractometer (Atago Automatic Compensation, ATC-1, Japan). A Shimadzu Mini-UV-Vis spectrophotometer was used to determine total reducing sugars and total sugars.

Digital Photometric Set-up

The digital photometric set-up used to take color photographs of mango fruits consisted of a light box made of plywood with two light emitting diodes (LEDs) placed inside the box. White color LEDs were mounted in sockets and were connected to line voltage (220 volts). A circular hole to fit the camera lens was made on the wall opposite the sample holder.

Image Acquisition

Static pictures of the mango samples were taken as peel color changed with stage of ripeness. The fruit samples were placed on the sample holder in the light box and pictures of two sides of the mango fruits were taken. Images of the fruits were taken using a 14.1 megapixel (GE E1450W) digital camera. The digital camera was set at ISO Automatic, which allowed automatic adjustment of the sensitivity of the camera's light sensor. The Macro setting was turned on to focus the lens at objects 5 cm away and its shutter speed was set at 4 ~ 1/2000 seconds (Manual 30 s). The flash option of the camera was turned off so that only light coming from the LEDs reached the sample.

Image Analysis of Fruit Peel Color

The RGB Analysis of Color Image software developed by Byers (2006) was used in color analysis of the static pictures of the fruit samples. RGB values were converted to CIE-L*a*b* values using Easy RGB free online color

converter software (https://www.easyrgb.com/en/convert.php). HSV values were calculated from RGB values.

Physico-chemical Properties of Mango Fruits

Pulp firmness. Mango fruit firmness was measured with a penetrometer (Imada MF push-pull instrument, Japan) inserted in the middle of the two faces of the mango fruit. Firmness values were expressed in pounds per square inch (psi).

Sample preparation. Mango pulp (20 g) was homogenized with distilled water at 1:5 (w/v) ratio in a blender and then filtered through cotton. The filtrate obtained was used in determining titratable acidity, acidity or pH, and total soluble solids.

Titratable acidity (TA). A 10-mL aliquot of the filtrate was titrated with standardized 0.1 N NaOH to phenolphthalein end point (AOAC 1995). Percent titratable acidity was expressed as meq citric acid per 100 g.

Acidity. Acidity of the mango fruit filtrate was determined by measuring its pH using a pH meter (YM, PHS-25 Analog, China) previously calibrated with pH 4.0 and pH 7.0 standard buffers.

Total soluble solids (TSS). Refractometry was used to determine the total soluble solids content of the fruits (AOAC 1995). Two to three drops of the filtrate were placed in a hand-held refractometer (Atago Automatic Compensation ATC-1, Japan). The results were expressed in ^{o}Brix units.

Total reducing sugars (TRS). The Nelson-Somogyi method (Somogyi 1952) was used to determine total reducing sugars. Absorbance was read at 540 nm using a Shimadzu Mini UV-Vis spectrophotometer using glucose as standard.

Total sugar (TS) and total starch (TSt). The phenol-sulfuric acid method (Dubois et al. 1956) was used to determine total sugars and total starch spectrophotometrically at 490 nm using standard glucose solutions.

Analysis of RGB Values and Some Physicochemical Properties

The R, G, and B values of the fruit samples were plotted against CI, as well as fruit pulp pH, titratable acidity, total soluble solids, reducing sugars content, total sugars content, total starch content, and firmness.

Statistical Analysis

A randomized experimental design with replications was carried out. Data were subjected to the ANOVA procedure. Duncan's Multiple Range Test (DMRT) of significance at 5% confidence interval determined significant differences between each peel color index. Correlation coefficients between RGB values and quality attributes were calculated using regression analysis.

RESULTS AND DISCUSSION

Correlation of Physico-chemical Characteristics with Stage of Ripeness

The pH of mango fruit pulp increased significantly with stage of ripeness while titratable acidity generally decreased (Table 1). Similar observations were reported by Okoth and co-authors (2013), Salvador-Figueroa (2011), and Abbasi and co-authors (2009) for Kenyan, "Ataulfo," and "Summer Bahisht Chaunsa" mango varieties, respectively. Firmness decreased significantly with ripeness.

Plots against stage of ripeness gave linearity coefficients of 0.967, 0.992, and 0.969 for TA, firmness, and pH, respectively; the latter parameters are useful indicators of ripeness.

Color Parameters for Mango Fruits at Different Stages of Ripeness

Separate plots of R, G, and B values against stage of ripeness gave correlation coefficient (R^2) values of 0.874, 0.931 and 0.915, respectively (Table 2). R^2 values for plots of color parameters based on the HSV (or HSB) and L*a*b* systems versus CI, which are given in Table 2, show that only V and L* had R^2 that were consistently greater than 0.9.

Color Functions and Degree of Ripeness

Color functions were formulated as combinations of R, G, and B values e.g., either as a binary function (combination of two colors R and G,) or as a ternary function (combination of three colors, R, G, and B). The equations for the color functions are:

$$C = \alpha R + \beta G \quad \text{(binary color function)} \quad (1)$$
$$C = \alpha R + \beta G + \gamma B \quad \text{(ternary color function)} \quad (2)$$

where α = R coefficient, R = R value, β = G value, G = G value, γ = B coefficient, B = B coefficient

The R, G, and B coefficients were obtained from the slopes of the plots of RGB values against TA and firmness values (Figures 1 and 2). The following cofficients were obtained:

For TA: α =-9.781, β = -1.938, γ = -10.092
For firmness: α = -7.892, β = -1.574, γ = - 8.304

The color functions for the corresponding physico-

Table 1. Physico-chemical properties of mango fruits at each stage of ripeness.

Stage of ripeness	pH	TA (% citric acid)	TSS (°Brix)	TRS (mM glucose)	TS (%)	TSt (%)	Firmness (psi)
1	3.20a	6.32d	4.4a	15.54a	17.33a	43.95c	5.42f
2	3.50b	5.12c	6.2a	18.34a	52.73bc	29.41b	4.24e
3	3.60bc	4.17b	12.1b	31.88a	83.62a	21.01a	3.14d
4	3.75c	3.29b	12.8b	51.25b	85.46a	17.87a	1.93c
5	3.85c	2.31a	13.3b	66.05b	63.56bc	16.47a	0.83b
6	4.10d	2.22a	15.6c	53.29b	45.74b	15.96a	0.24a

Values are means of three replicates. Treatment means in a column followed by the same letters are not significantly different (5% DMRT).

Table 2. Correlation coefficients of RGB, HSV and L*a*b* color parameters for color index/stage of ripeness, titratable acidity, and firmness of mango fruits.

Color parameters	Correlation coefficient (R^2)		
	Color index / Stage of ripeness	Titratable acidity	Firmness
R	0.874	0.917	0.941
G	0.931	0.948	0.941
B	0.915	0.915	0.933
H	0.761	0.817	0.789
S	0.700	0.676	0.713
V	0.931	0.948	0.941
L*	0.948	0.977	0.968
a*	0.867	0.904	0.895
b*	0.491	0.453	0.497

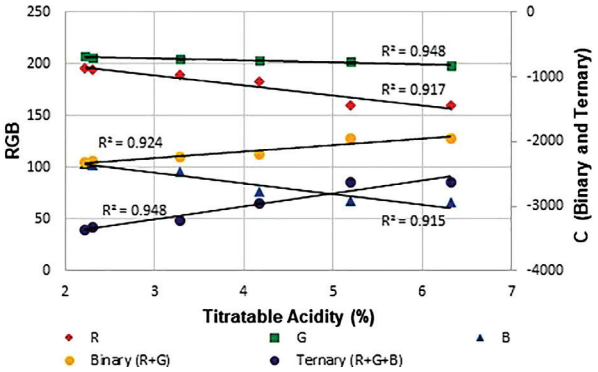

Figure 1. Correlation of RGB and C (binary and ternary functions) with titratable acidity of mango fruits.

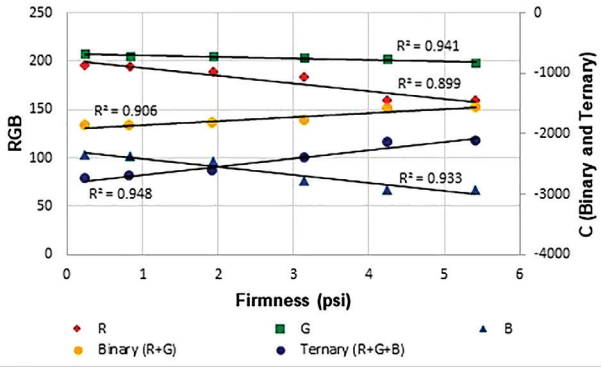

Figure 2. Correlation of RGB and C (binary and ternary functions) with firmness of mango fruits.

chemical parameters were formulated as follows:

For TA:

$$C_{binary} = -9.781R - 1.938G \quad (3)$$

$$C_{ternary} = -9.781R - 1.938G - 10.092B \quad (4)$$

For firmness:

$$C_{binary} = -7.892R - 1.574G \quad (5)$$

$$C_{ternary} = -9.892R - 1.574G - 8.304B \quad (6)$$

The calculated values of the color functions were then plotted against TA and firmness. The linearity coefficients for TA were 0.924 and 0.948, respectively, for the binary and ternary C functions; corresponding values for firmness were 0.906 and 0.948, respectively. As shown in Figure 1 (separate RGB values versus titratable acidity), the linearity coefficients for R, G, and B are 0.917, 0.948, and 0.915, respectively. Figure 2 shows the corresponding coefficients relative to firmness as 0.899, 0.941, and 0.933. However, the slopes of the plots for G are close to zero, which indicates that the G color function is not a sensitive indicator of ripeness. The observed coefficients for the

ternary C function versus fruit ripeness indicators (TA and firmness) are higher than those for the binary C function (containing G and B values) and for all (except one) of the separate RGB plots. Only G and B values were considered in formulating the binary color function in the present study; two alternative binary functions i.e., involving R+G and R+B values, were not evaluated. However, it is expected that the ternary color function is a better color indicator of mango fruit ripeness compared to that involving only one or two (binary color function) of the RGB values because the three primary colors are included in the ternary color function and hence, gives a more quantitative description of fruit color. Domingo and co-authors (2012) reported similar results for 'Sinta' papaya fruits.

As shown in Table 2 and Figures 1 and 2, the L* and RGB ternary color functions showed consistently the highest correlation with titratable acidity (TA) and firmness; these color parameters, therefore, are useful quantitative indicators of mango fruit ripeness.

The digital photometric method, which was studied in the present paper, is mainly suited in the laboratory where a fabricated wooden light box is used for taking color photographs of the mangoes and color analysis of the taken images requires a computer. Further research is needed in order to develop and adapt the method for machine sorting of mangoes. Thus, the conventional subjective method based on visual comparison of mango fruit color with the color index (CI) is simpler and more practical in the field for manual sorting of harvested mangoes.

CONCLUSIONS

RGB values generated from digital images were used to derive the ternary color function C, which correlated highly with TA and fruit firmness; the latter parameters were found to be good indicators of mango fruit ripeness. The color function C and L* (lightness), which is based on the L*a*b* system, were found to be quantitative indicators of mango ripeness. The results of the present study demonstrated that digital photometry, using a digital camera and free-access software for color analysis, can be used as a quantitative laboratory method to determine the degree of ripeness of mango fruits. This computer-based method is an alternative to the conventional subjective technique for evaluating mango fruit ripeness.

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